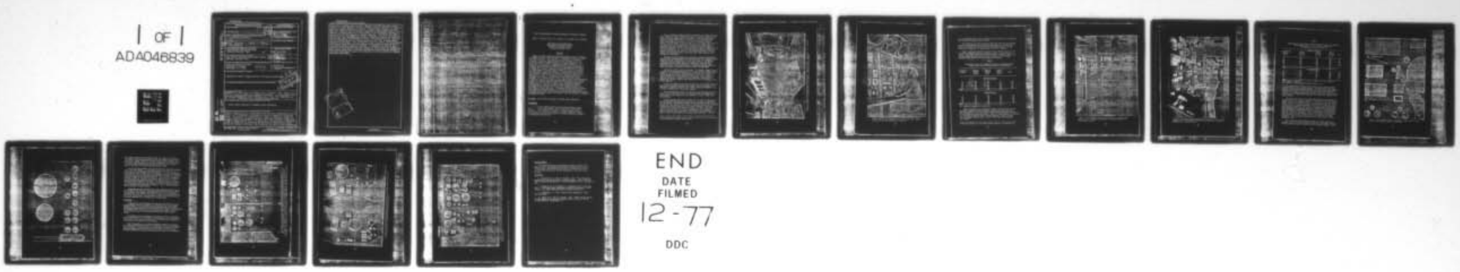
AD-A046 839 NAVAL MEDICAL RESEARCH INST BETHESDA MD F/G 14/2
SAFETY CONSIDERATIONS IN HUMAN ENGINEERING OF HYPERBARIC EQUIPM--ETC(U)
OCT 77 A J BACHRACH, W W BANKS, D M HEANEY

UNCLASSIFIED NL

1 OF 1
ADA046839



END
DATE
FILMED
12-77
DDC

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

AD A046839

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
(6) SAFETY CONSIDERATIONS IN HUMAN ENGINEERING OF HYPERBARIC EQUIPMENT.

5. TYPE OF REPORT & PERIOD COVERED
(12) (9) Medical Research Progress Report,

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
(10) Arthur J. Bachrach, W. W. Banks, D. M. Heaney, and G. Goehring

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Naval Medical Research Institute
Bethesda, Maryland 20014

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
M0099-PN.03.3022
Report No. 2

11. CONTROLLING OFFICE NAME AND ADDRESS
Naval Medical Research & Development Command
Bethesda, Maryland 20014

12. REPORT DATE
(11) Oct[redacted] 1977

13. NUMBER OF PAGES
15 pages

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
Bureau of Medicine & Surgery
Department of the Navy
Washington, D.C. 20372

(12) 17p.

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release and sale; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES
Bachrach, A.J., W.W. Banks, D.M. Heaney, and G. Goehring. 1977. Safety considerations in human engineering of hyperbaric equipment. In; Proceedings of the Third International System Safety Conference, Oct. 17-21, 1977, Washinton, D.C. pp. 23-37. Washinton,D.C., System Safety Society.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

system safety; hyperbaric equipment; human engineering

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Recent increased interest in deep ocean diving has been accompanied by a marked increase in the development of hyperbaric research in support of diving operations. This research is concentrated in a number of industrial, university, and Navy laboratories throughout the world, which have hyperbaric chamber complexes of varying capabilities. The deeper ones, with pressures to approximately 904 psi (2000 ft), are located at the University of Pennsylvania, Taylor Diving and Salvage of Louisiana, Duke University, and the U.S. Navy Experimental

AD No.
DDC FILE COPY

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

UNCLASSIFIED 249 650

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

Diving Unit in Panama City, Florida. Recently installed and under current testing is a deep chamber at the Naval Medical Research Institute in Bethesda, which has manned capability of 1500 psi. Because human subjects are under hyperbaric pressure and are therefore subjected to marked physiological stress, there is a strong concern for system safety in the development, maintenance, and operation of such hyperbaric chamber complexes. Yet it has only been in recent years that the hyman engineering of hyperbaric chambers and supporting consoles has begun in a systematic fashion. The Defense and Civil Institute of Environmental Medicine in Toronto was one of the first to employ human engineering techniques. This presentation covers an analysis of human engineering problems associated with the complex at the hyperbaric research facility at the Naval Medicial Research Institute. A systematic approach to these problems, which assessed scale-model mockups of the facility, has demonstrated that proper human factors engineering optimizes operator/system performance, minimizes physiological costs to the operator, and can contribute to improved efficiency and safety.

UNCLASSIFIED

PROCEEDINGS OF THE...

THIRD INTERNATIONAL SYSTEM SAFETY CONFERENCE

October 17–21, 1977

STOUFFER'S NATIONAL CENTER INN

Washington, D.C.

Sponsored by

THE SYSTEM SAFETY SOCIETY

SAFETY CONSIDERATIONS IN HUMAN ENGINEERING OF HYPERBARIC EQUIPMENT

Arthur J. Bachrach, Ph.D., W. W. Banks, D. M. Heaney, and G. Goehring

Behavioral Sciences Department
Naval Medical Research Institute
National Naval Medical Center
Bethesda, Maryland 20014

Abstract

Recent increased interest in deep ocean diving has been accompanied by a marked increase in the development of hyperbaric research in support of diving operations. This research is concentrated in a number of industrial, university, and Navy laboratories throughout the world, which have hyperbaric chamber complexes of varying capabilities. The deeper ones, with pressures to approximately 904 psi (2000 ft), are located at the University of Pennsylvania, Taylor Diving and Salvage of Louisiana, Duke University, and the U.S. Navy Experimental Diving Unit in Panama City, Florida. Recently installed and under current testing is a deep chamber at the Naval Medical Research Institute in Bethesda, which has manned capability of 1500 psi. Because human subjects are under hyperbaric pressure and are therefore subjected to marked physiological stress, there is a strong concern for system safety in the development, maintenance, and operation of such hyperbaric chamber complexes. Yet it has only been in recent years that the human engineering of hyperbaric chambers and supporting consoles has begun in a systematic fashion. The Defense and Civil Institute of Environmental Medicine in Toronto was one of the first to employ human engineering techniques. This presentation covers an analysis of human engineering problems associated with the complex at the hyperbaric research facility at the Naval Medical Research Institute. A systematic approach to these problems, which assessed scale-model mockups of the facility, has demonstrated that proper human factors engineering optimizes operator/system performance, minimizes physiological costs to the operator, and can contribute to improved efficiency and safety.

Key Words: system safety; hyperbaric equipment; human engineering.

INTRODUCTION

[illegible] the past decade industrial and military interest in deep ocean [illegible]ing has risen sharply. Parallel with this rising interest has b[illegible] a [illegible]owing emphasis on hyperbaric research directed toward solving [illegible]-dive operational problems. At present there are a number of U.S. laboratories that are equipped with special hyperbaric equipment of varying depth capabilities.

It is a tribute to design engineers and hyperbaric chamber operators that, despite the tens of thousands of hours of operation under pressure, there has been a minimum number of accidents. With this good safety record, one might wonder why we emphasize safety considerations and human engineering in our studies. It is for a simple yet crucial reason: in this field, as in many others, it is our belief that operators are required too often to compensate for inadequate design aspects of equipment (Bachrach and Egstrom [1]) requiring effort that leads to successful operation, but at an undetermined performance and physiological cost to the operator. It is likely that fatigue factors in hyperbaric chamber operation are one result of such energy expenditure. We would suggest that optimizing human engineering would reduce operator effort and improve performance.

Problems of human engineering of hyperbaric chambers and underwater habitats and submersibles have long been recognized, but little systematic research has been accomplished. In the final report of the SEALAB II underwater habitat program (Pauli and Clapper [4]) over half of the recommendations for future changes in the habitat design are human factors concerns, many of which (such as inadequate lighting around the shark cage area) are directly related to safety considerations.

Few systems are free of such problems. For example, Figure 1 shows a solution to a problem perceived after the installation of the hyperbaric chamber at the Royal Naval Physiological Laboratory at Alverstoke, U.K. It was necessary to build a wooden platform to raise the operator so that he could follow the recordings on the gauges. Figure 2 shows a operator seated at a console at the Navy Experimental Diving Unit in Panama City, Florida. Many of the controls are out of the reach or view of the operator.

It was our purpose in analyzing the plans for the recently installed Naval Medical Research Institute deep chamber complex (pressures up to 1500 psi) to approach the plans from a human engineering standpoint and to offer recommendations for possible changes.

At these pressures, men will be exposed to physiological and psychological stress; therefore, there is a marked concern for system safety development, control operation, and maintenance of these complex hyperbaric systems.

Recognizing that plans may be altered in the course of construction, we took the existing plans as submitted by the contractor as the basis for the studies. We had scale mockups of the hyperbaric control equipment constructed, and using U.S. Navy divers as operator subjects, we conducted a human engineering evaluation of the control consoles.* From this evaluation, we were able to identify a number of problem areas common to many of these systems and to make recommendations for alternative hardware designs, which we believed would improve operator/system performance, safety, and efficiency during actual system operation. During

---

*Future studies of a similar nature will be conducted on the scale mockup of the hyperbaric chamber complex itself.

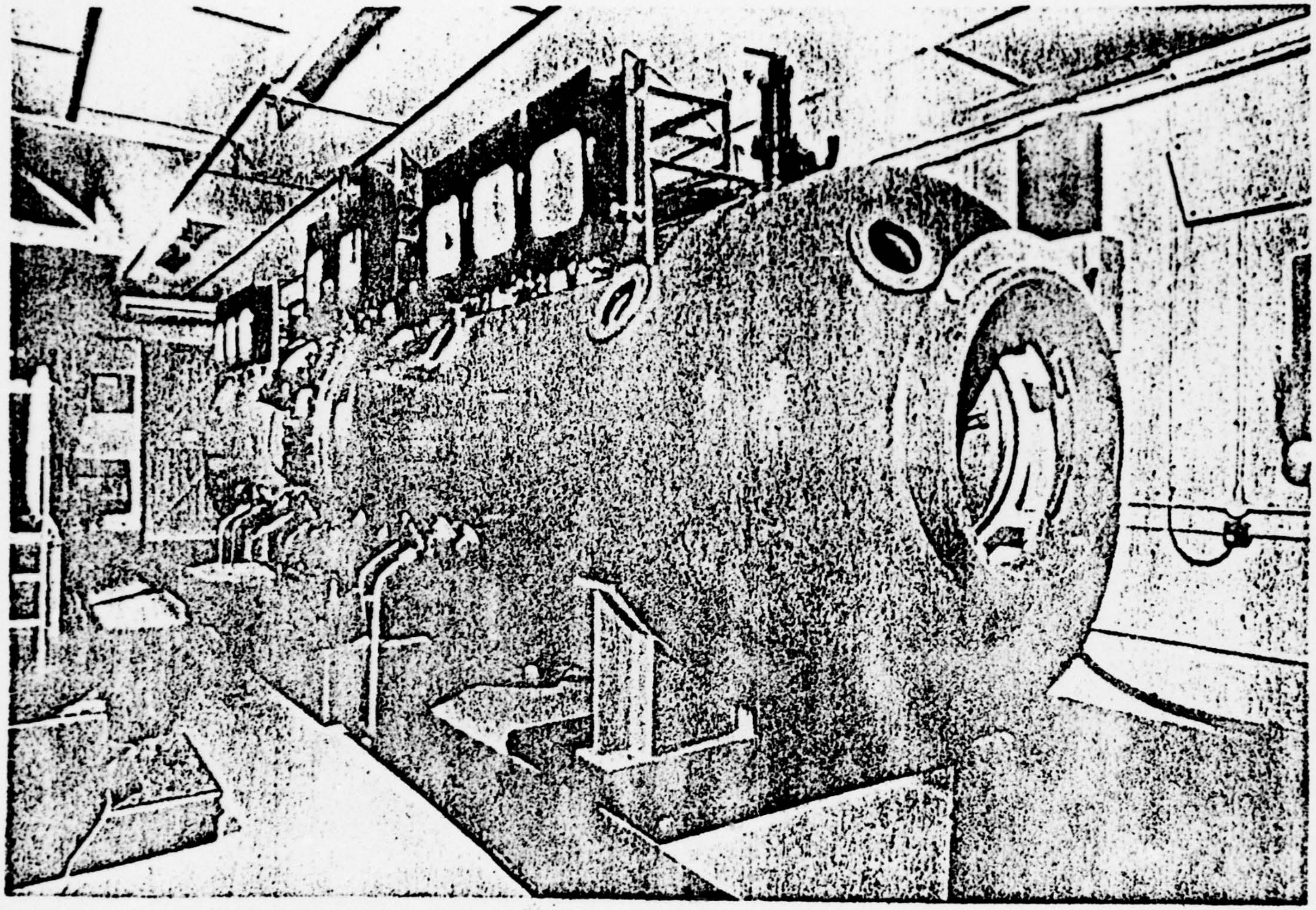


Fig. 1. Chamber at the Royal Naval Physiological Laboratory (RNPL), Alverstoke, U.K., required a wooden stand to make gages visible and operable. (Photo courtesy of RNPL)

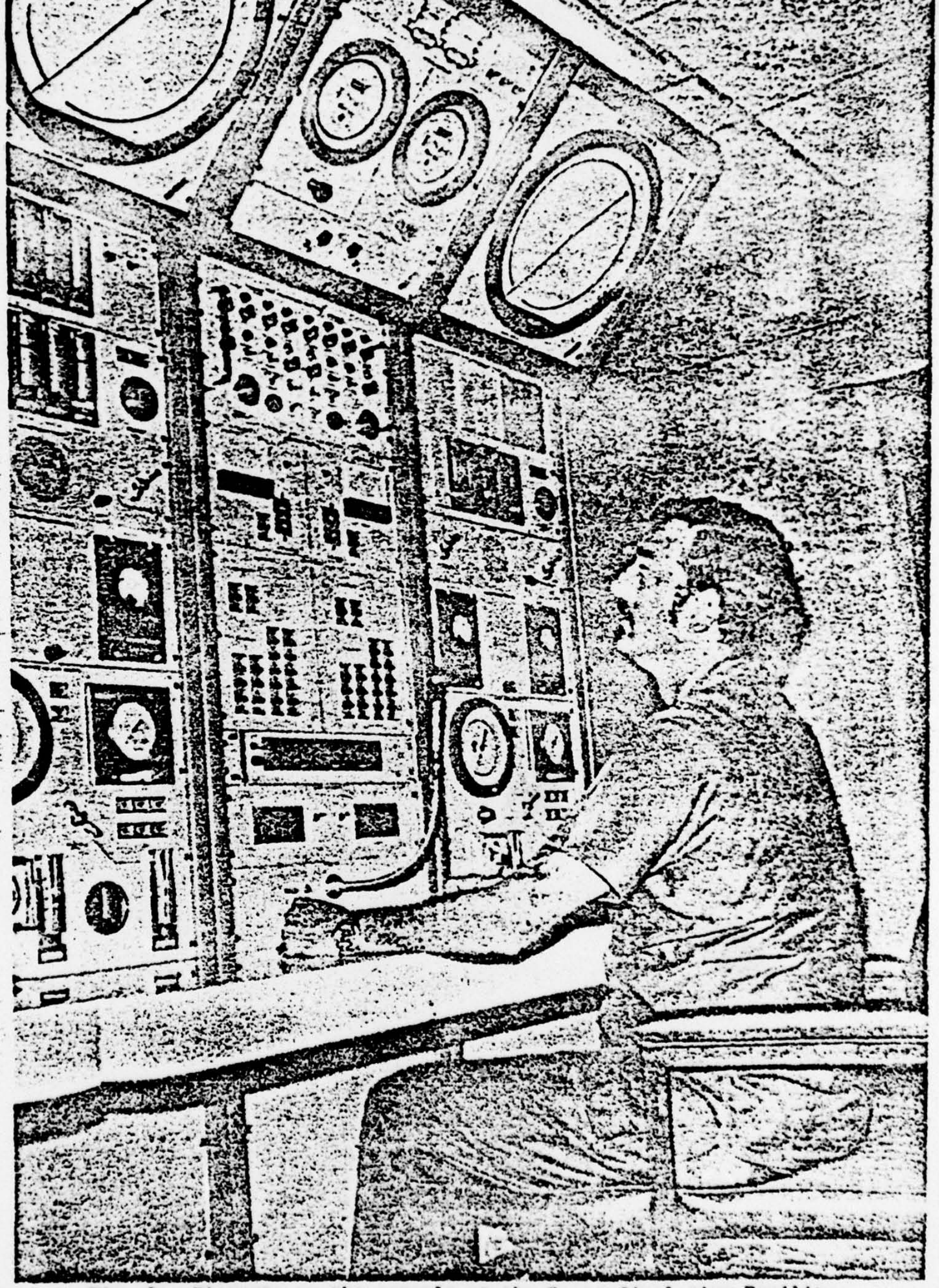


Fig. 2. Elements on the console at the Ocean Simulation Facility, Panama City, Fla., are difficult for an operator to view. (Photo courtesy of U.S. Navy Experimental Diving Unit)

our investigation under static and dynamic test conditions, we classified five sources of possible safety concern.

The first area of concern became evident when operators of different heights had difficulty in reaching high-use components. In addition, a number of critical view meters had been suboptimally placed, causing parallax and difficulty in making quick, error-free readings.

Table 1 indicates the wide range of operator ability (as a function of height) required to operate components on each of three control panels. This table demonstrates an often observed problem in hyperbaric control design that may cause operators of small and medium height discomfort and irritation during a deep-dive operation.

TABLE 1

Percentage of controls reached by seated or standing operators using control panels #3007870, #3007871, and #3007872

Percentile Height	Panel # 3007870 *n=50	Panel # 3007871 n=32	Panel # 3007872 n=35	Mean
		Standing Position		
5	.54	.81	.71	.58
25	.60	.81	.71	.70
50	.64	.81	.80	.75
75	.88	.93	.80	.87
95	.88	.93	.94	.91
Mean	.70	.85	.79	
		Seated Position		
5	.44	.68	.42	.51
25	.44	.68	.51	.54
50	.50	.78	.60	.62
75	.50	.78	.65	.64
95	.54	.81	.71	.68
Mean	.48	.74	.57	

*n = number of components in each panel

Table 2† displays the percentage of meters optimally placed in the operator's field of view from both his standing and seated positions. The optimum field of view was defined as any viewing angle less than 30° from the head-on, eye-to-meter angle. There is a large degree of variability as a function of operator height in the percentage of meters falling into the optimal viewing angle. Figures 3 and 4 show this situation more clearly.

†Tables and figures are from Banks, Heaney, Bachrach, and Goehring [2].

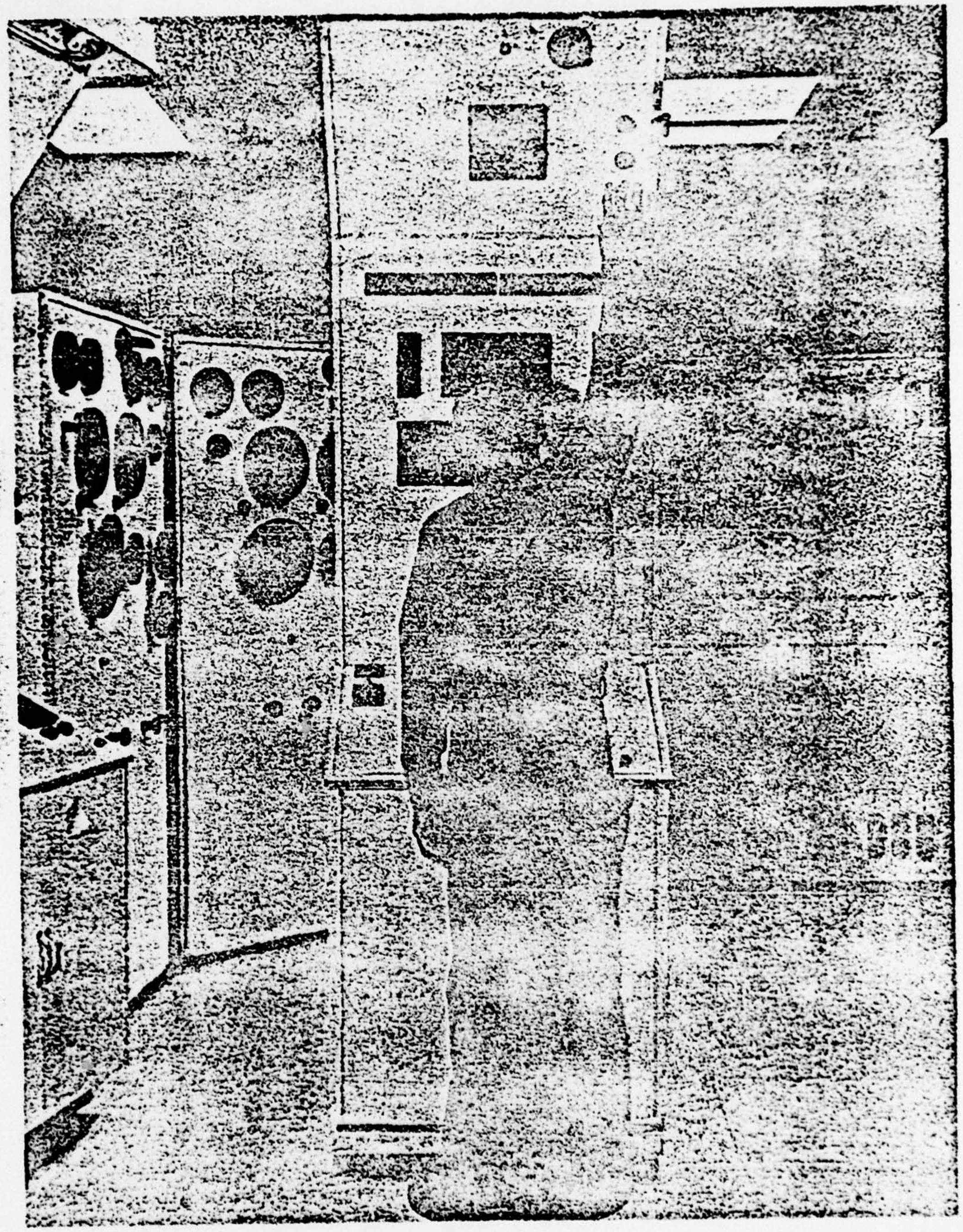


Fig. 3. Panel #3007872 was rated unsatisfactory in regard to the specification of component accessibility. (The human operator is 5 ft 10 inches tall.)

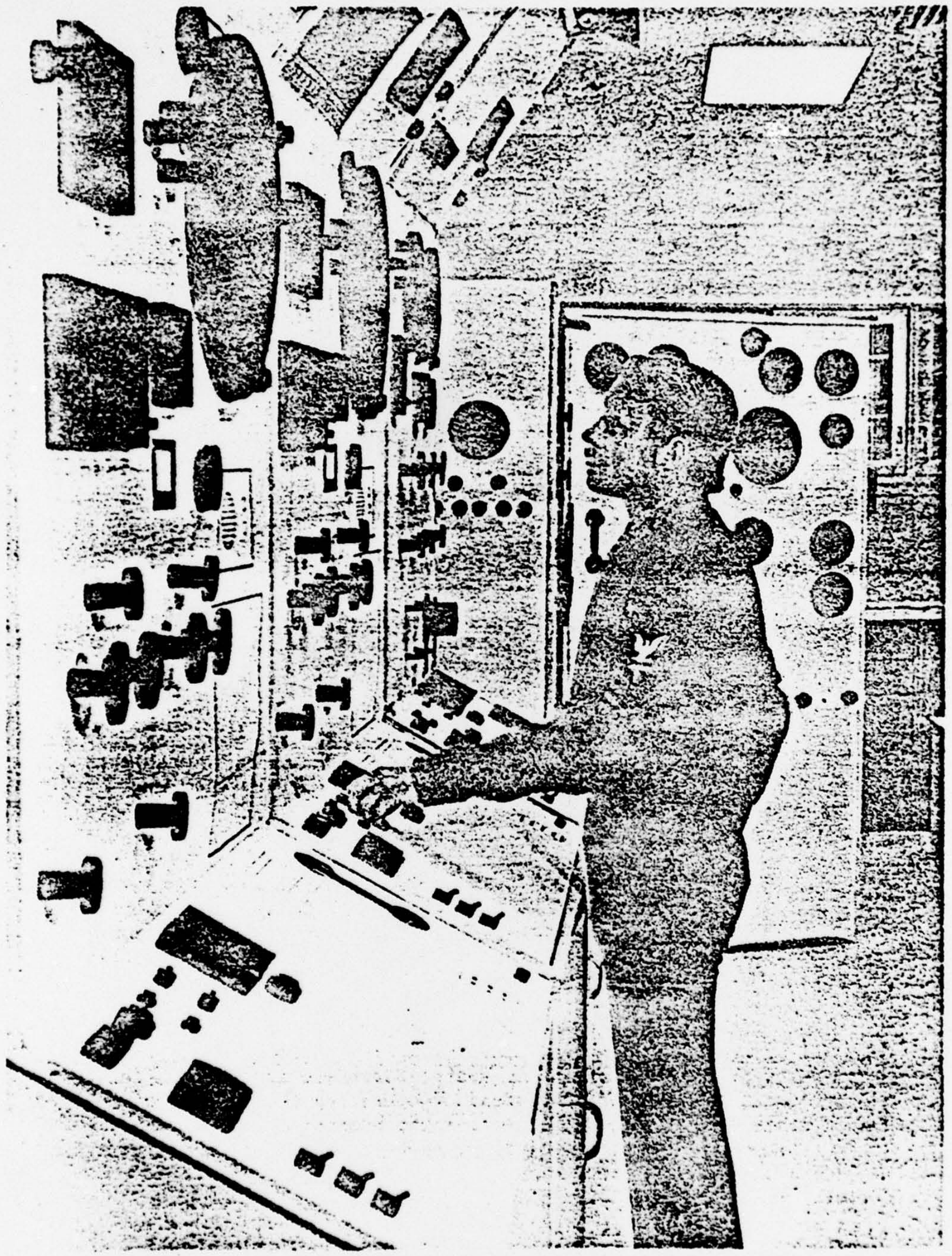


Fig. 4. The large, round pressure meters are located too high on the control panel for optimizing the operator's viewing field. (The human operator is 5 ft 10 inches tall.)

TABLE 2

Percentage of visual display meters and gages within the criterion 30° viewing angle across all 3 control panels for the standing and seated operator

Percentile Height *n = 5	Panel # 3007870 †N = 19	Panel # 3007871 N = 26	Panel # 3007872 N = 15	Mean
		Standing Position		
5	.63	.57	.53	.57
25	.63	.57	.53	.57
50	.63	.80	.53	.65
75	.84	.80	.66	.76
95	.89	.80	.66	.78
Mean	.72	.70	.58	
		Seated Position		
5	.15	.42	.26	.27
25	.21	.42	.26	.29
50	.26	.42	.26	.31
75	.52	.42	.60	.51
95	.52	.42	.60	.51
Mean	.33	.42	.39	

*n = number of subjects.
†N = number of visual displays (gages, meters, etc.)

The second area of concern was directed at the spacing between certain emergency and override controls. The oxygen controller valves (manual) were placed so closely together that the operator was unable to turn any one of these three valves without scraping his knuckles or fingers or accidentally turning the adjacent valve knob. Figure 5 shows most clearly this undesirable situation, which certainly detracts from design safety.

The third area, found to be "questionable" from the standpoint of design safety, can be seen in Figure 6. The emergency fire activation handle, attached to a movable lanyard, was placed very near the sanitary drain controls. The possibility that this swinging handle could inadvertently activate pressure-sensitive controls, or collide with glass-faced meters bothered us. As a result, recommendations for relocating and redesigning this component were made. Figure 6 also demonstrates that the design of the sanitary drain system failed to incorporate the idea of "sequential operation." Instead of operating this system by activating controls in a smooth, left-to-right fashion, we discovered that the operator must use left-to-right, then right-to-left hand movements. This particular system can also be improved by a better sequential layout.

Our fourth area of concern was the poor functional grouping of controls. Ideally, for the efficient operation of hyperbaric controls, all functionally related components should be grouped together, which

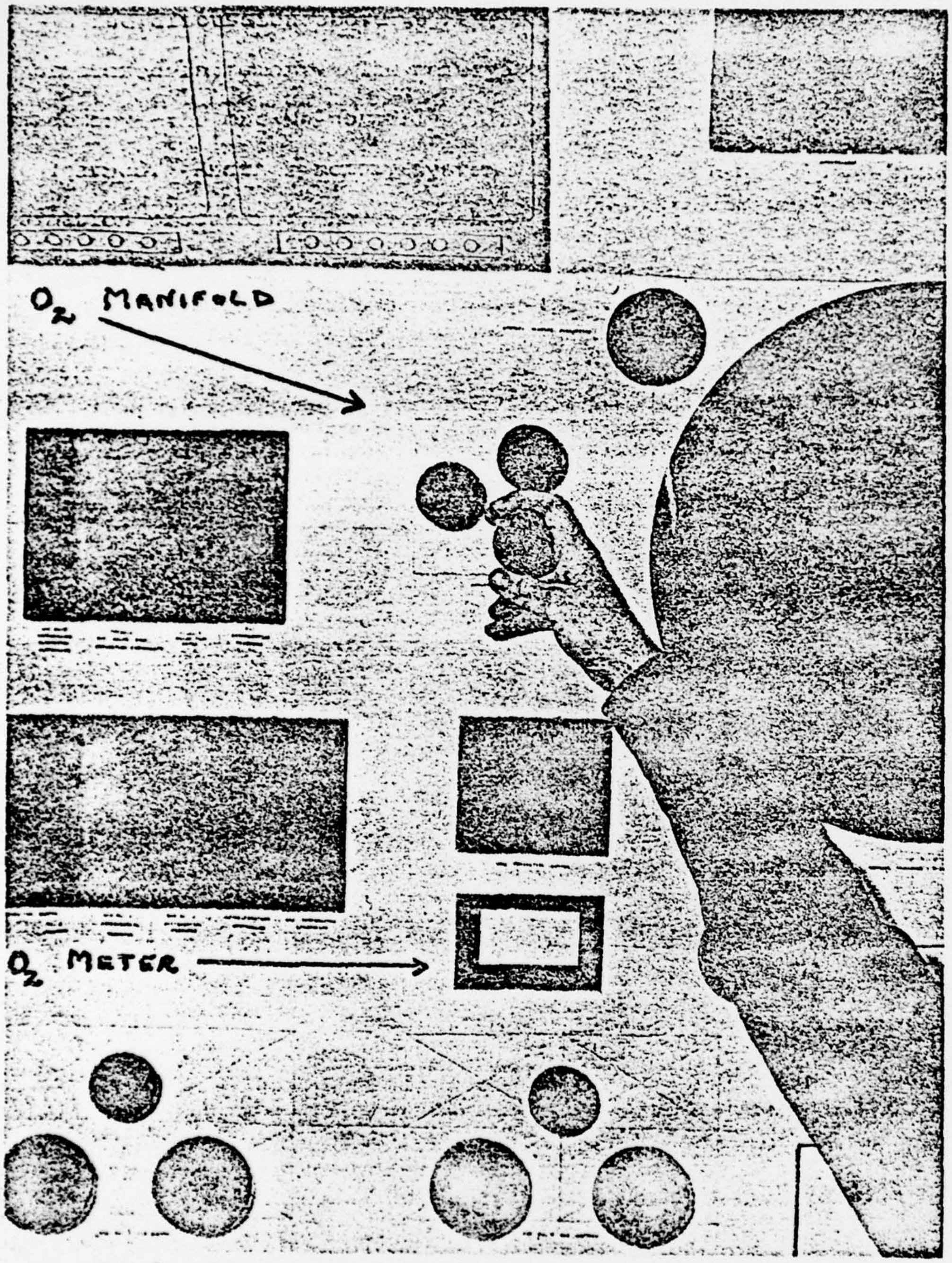


Fig. 5. The placement of the O_2 manifold in relationship to the O_2 meter is shown (panels #3007870 and #3007872).

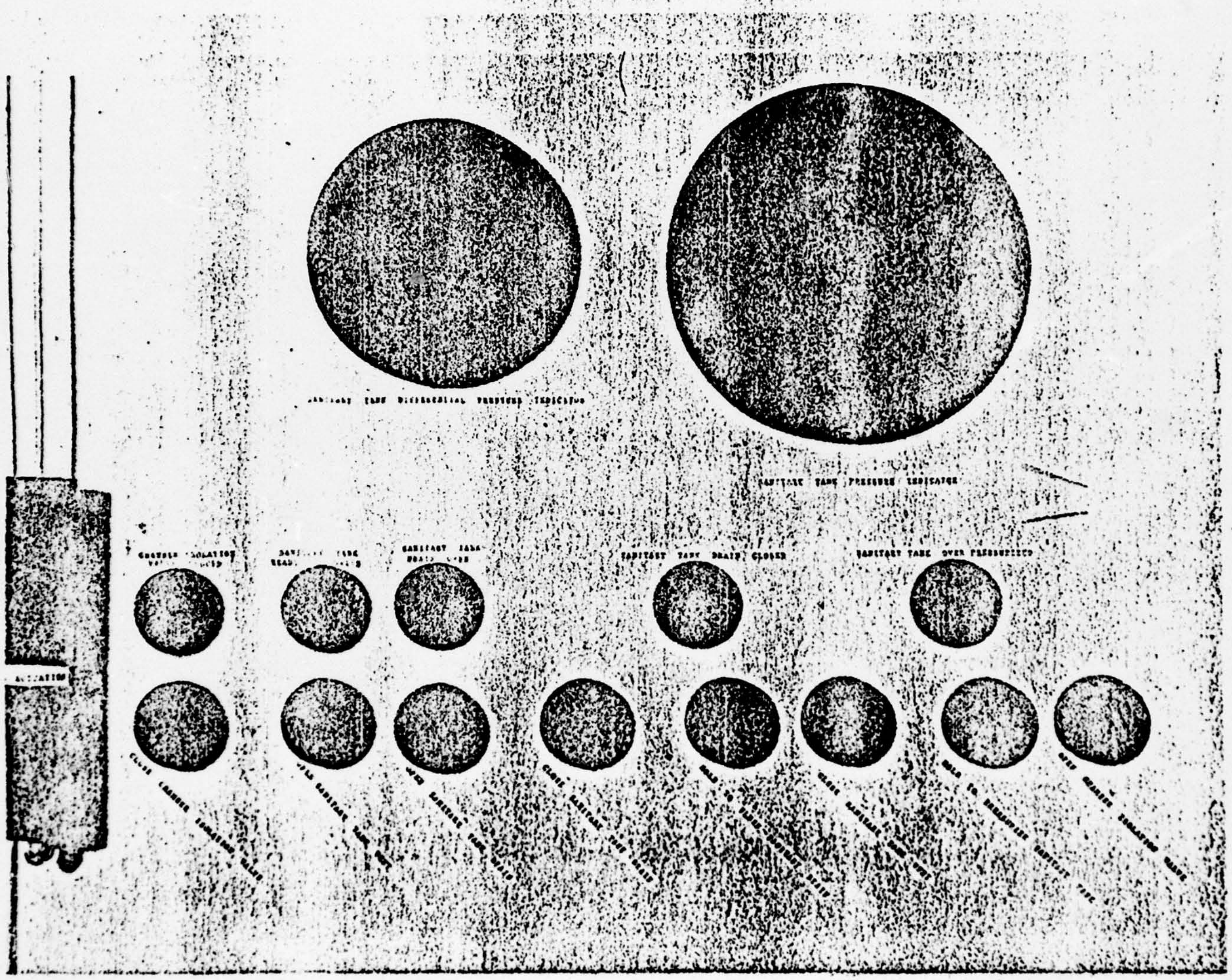


Fig. 6. Side panel local #3007874 is used for sanitary draining. Control/indicator relationships

will require fewer operator movements (Fig. 7). Figure 7 shows the relatively wide physical separation of the environmental controls from each other. Figure 8 shows an alternate design, which rectifies the problem by grouping together all of the environmental controls beneath the large, round pressure gage displayed in the picture. In this manner, they are all in good visual and physical reach.

One of the last problems we encountered was an inappropriate design that could cause damage to a particular pressure gage (Fig. 9). We found that two pressure gages on one local panel were used to read the same pressure. One of these meters was designed to be read for pressures between 0 and 193 psi (400 feet); the second was intended to be read for pressures between 0 and 1216 psi (2700 ft). If an operator exceeded a pressure of 193 psi, he would first have to shut off the 0- to 193-psi meter and switch his attention to the 0- to 1216-psi meter. If the operator doesn't remember to do this, or if he initially monitors the 0- to 1216-psi meter while the other meter is turned on, the low pressure gage will break and require factory repairs. Such a situation poses a serious problem of system safety.

Associated with this problem, Fig. 9 also demonstrates that some of the pressure meters had their associated meter shut-off valves inconsistently placed. For example, on some meters this valve was physically located on the lower right of the meter; on others it was located on the lower left of the meter. This situation is quite undesirable because it may cause confusion and it reflects poor systems design.

DISCUSSION

We believe (as does McCormick [3]) that the responsibility for the actual physical design of components is essentially that of the design engineer; however, a developmental stage is needed during which human engineering recommendations can be considered. Well-prepared recommendations can eliminate many "system bugs" that otherwise will plague the users during the life cycle of the system and may possibly reduce system safety.

The examples we have presented do not reflect all the of potential safety risks uncovered. We believed it more beneficial to create general categories of these specific problems and to provide graphic examples of them, instead of presenting each discrepancy.

From the standpoint of the control designs we examined, we believe too little attention has been paid to the ultimate users of these systems (the operators). Because of this, the system will not display the high degree of engineering technology that can be expected from the truly ingenious hardware that has been incorporated into many of its subsystems.

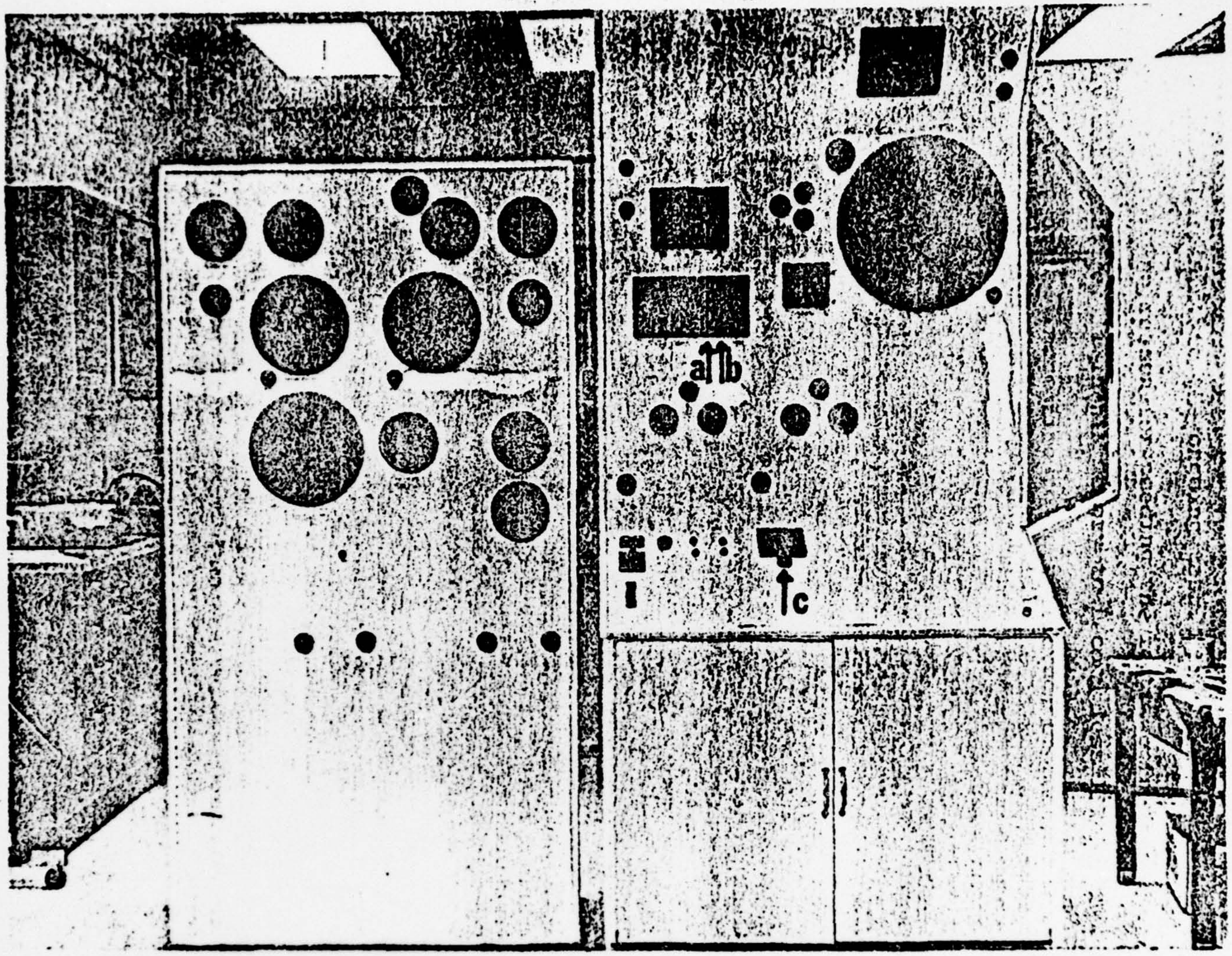


Fig. 7. MRCC panel #337870: The components of the environmental control system labeled A, B, and C are displaced. Note that they are not grouped together, but are separated by 23 inches. In addition, controls A and B appear to comprise part of the BIB gas meter controls.

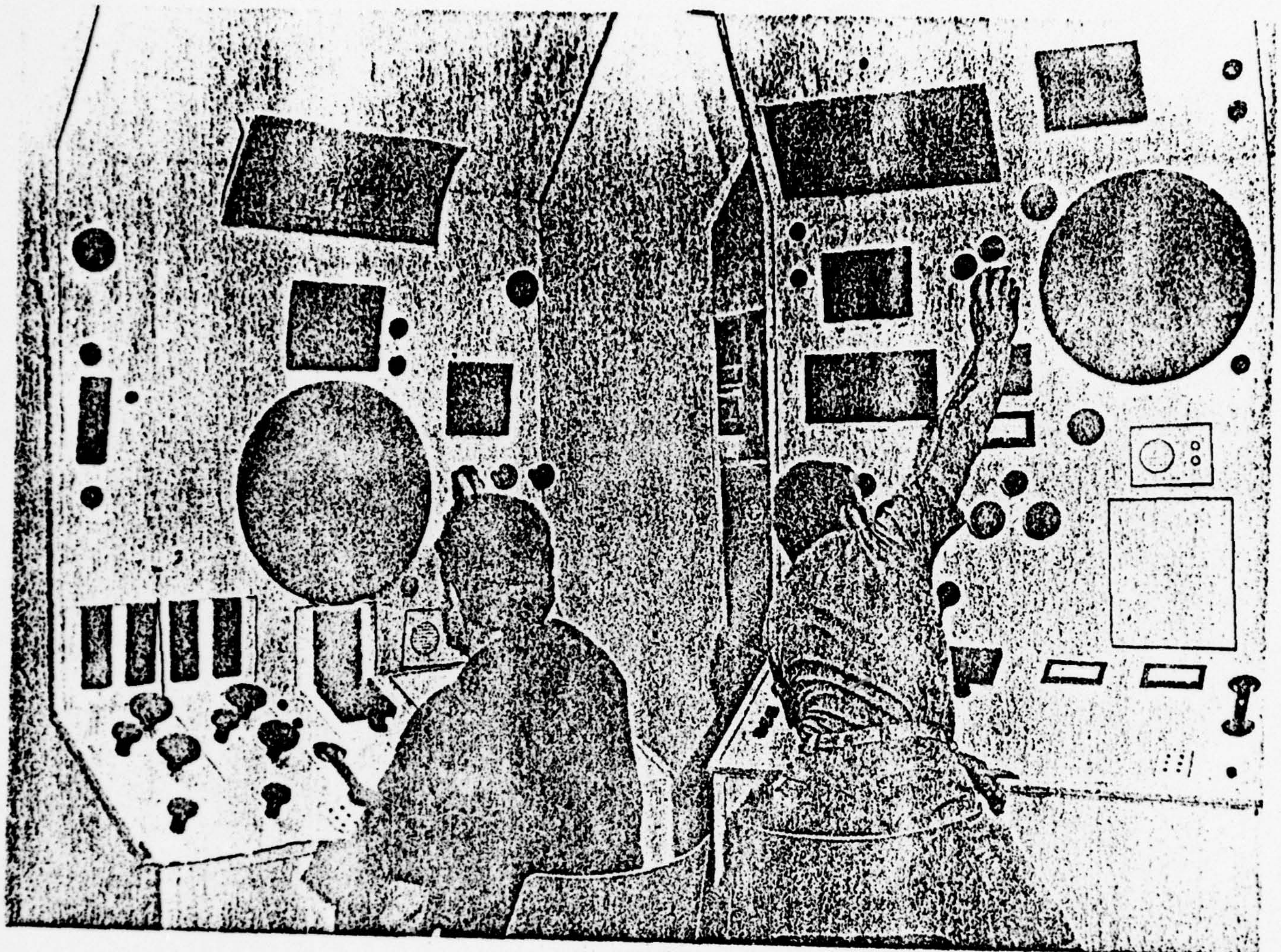


Fig. 8. The right console mockup was constructed from contractors' plans; the left is a modification based on preliminary human factors studies.

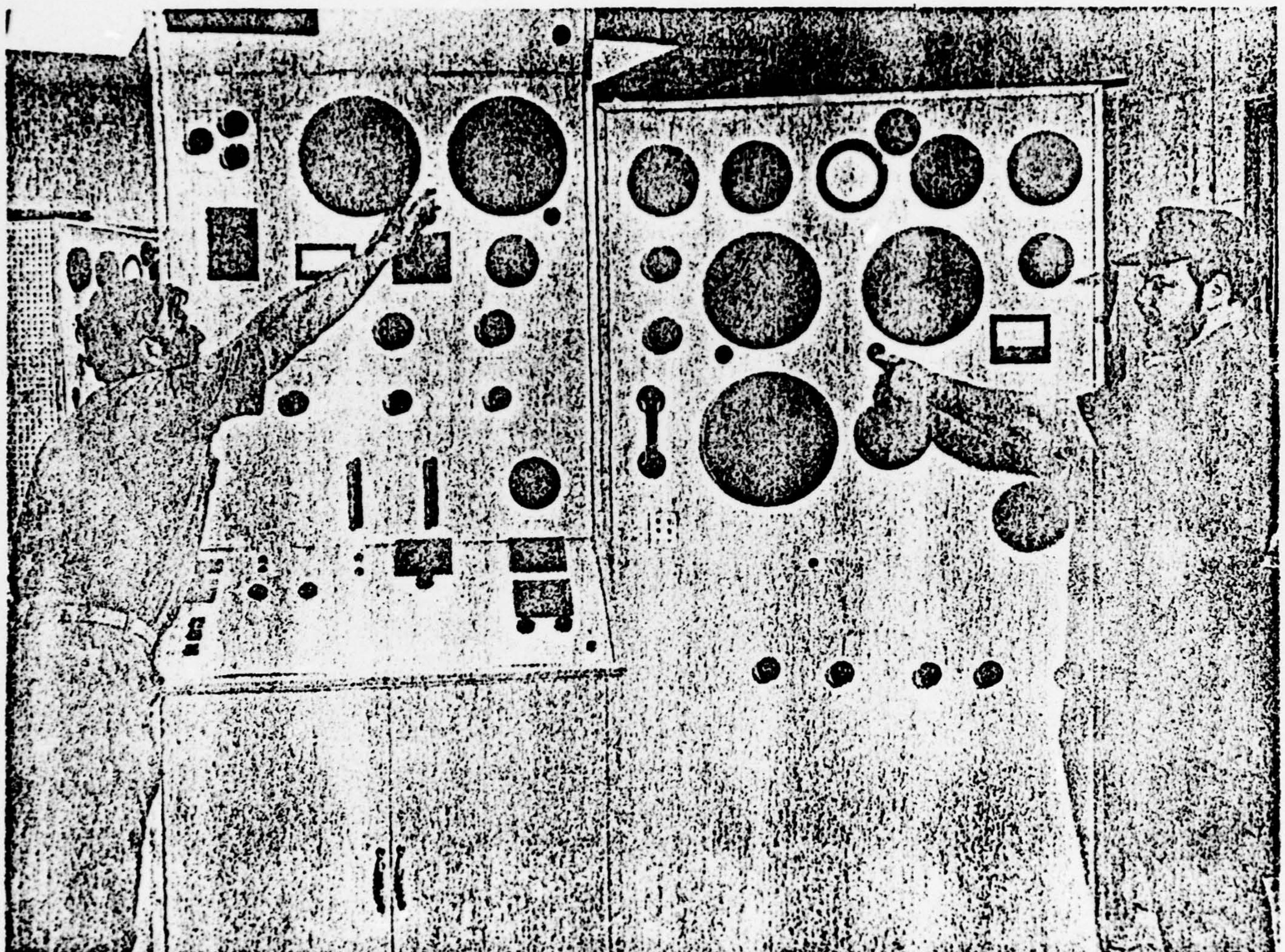


Fig. 9. Control panel #3007874 (right) has its control meter shut-off valves inconsistently placed in relation to control panel #3007872 (left). The men in the picture are pointing to these controls.

ACKNOWLEDGMENTS

Naval Medical Research and Development Command, Research Task MPN10.03.3022. The opinions and statements contained herein are the private ones of the writers and are not to be construed as official or reflecting the views of the Navy Department or the Naval Service at large.

REFERENCES

1. Bachrach, A. J., and G. H. Egstrom. 1974. Human engineering considerations in the evaluation of diving equipment. Pages 203-218 in The Working Diver Symposium 1974. Marine Technology Society: Washington, D.C.

2. Banks, W. W., D. M. Heaney, A. J. Bachrach, and G. S. Goehring. 1977. A preliminary human engineering evaluation of hyperbaric control systems. U.S. Naval Medical Research Institute, Bethesda, Md.

3. McCormick, E. S. 1970. Human factors engineering. McGraw Hill, New York.

4. Pauli, D. C., and G. P. Clapper. 1967. Project SEALAB Report: An experimental 45-day undersea saturation dive at 105 feet. Office of Naval Research, Washington, D.C.